Analysis of Observed and Modeled Surface Fluxes, Cloud Forcing, and Convective Processes for Improving The Meteorological And Oceanographic Modeling And Prediction Systems

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LONG TERM GOAL

The United States Navy is the Department of Defense's main source for standard meteorological and oceanographic predictions (METOC). At the heart of these predictions are the short-to-medium range weather forecasts produced by the Navy Operational Global Atmospheric Prediction System (NOGAPS). In addition to providing weather forecasts, this system provides forcing (i.e. surface fluxes) to the oceanographic prediction systems. Given the prominent role surface fluxes play in both these systems, it is vital they be properly simulated by NOGAPS. Presently, there are significant shortcomings in the NOGAPS simulation of the surface energy budget over the ocean. These shortcomings are mostly associated with mean surface latent and net solar heat flux biases that can be as large as 50 Wm^{-2} or more in a number of tropical/subtropical areas. The long term goal of this research is to determine the underlying causes for these shortcomings in order to: 1) enhance NOGAPS physical representation of the atmosphere and extend the skill of its medium range weather predictions, and 2) improve the skill of the oceanographic and coupled prediction systems via the improved simulation and prediction of the surface energy budget.

OBJECTIVES

The objectives of this research are to: 1) identify the parameterizations and processes which underlie NOGAPS' surface heat flux biases; 2) develop observed surface flux data sets over the ocean, particularly for shortwave, that can be used to identify and diagnose model-data discrepancies; 3) diagnose the shortcomings in the physical parameterizations used by METOC atmospheric models, and 4) help assess the observational strategies employed by atmospheric field programs.

APPROACH

The approach taken in this research effort can be broken down into the following parts:

1) Assemble satellite-based and ground-based verification data sets for diagnostics comparison of NOGAPS simulation output. Perform the analysis/comparison on the climatologies of the NOGAPS output and the available observations. Focus the analysis on those areas that show greatest surface flux discrepancies with observed data and consider the linkages between the

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dynamics and the hydrological and energy cycles of the system in order to try and identify the underlying causes for the surface flux biases in the model.

2) Using buoy-observed values of surface shortwave flux and a single-column version of the NOGAPS, validate the modeled clear-sky surface solar radiation flux values. This comparison will help to isolate the causes of the shortwave flux biases. One of the main steps in accomplishing this task is assembling a robust open-ocean set of shortwave observations, necessarily from moored buoys, and developing a technique to filter out the cloudy periods from these records. This latter step allows the clear-sky samples to be used in conjunction with a well-validated clear-sky shortwave model to in turn examine the efficacy of moored buoys to make robust measures of surface shortwave.

3) Typically, data from field programs are used to calculate vertical velocities and advective tendencies that can then be used to study large-scale processes and budgets, examine the subgrid-scale influence on the resolvable fields, and assess model parameterizations. The Zhang and Lin (1997) variational analysis, presently used on ARM and COARE data, produces a "best" estimate of the adjustments to the observed data (which are influenced by small-scale variability and sampling errors) so they conserve mass, moisture, momentum and energy. By using the cloud-resolving Coupled Ocean/ Atmosphere Mesoscale Prediction System (COAMPS) model as a form of synthetic observations, the variational scheme can be validated and/or evaluated for possible shortcomings. In addition, if the scheme can be proven to have benefit, it can be used in conjunction with COAMPS output to help determine the optimal sampling strategies for atmospheric sounding arrays.

4) From the model-observation comparisons described above, and in collaboration with the NRL modeling teams, determine the underlying causes for the NOGAPS parameterization deficiencies that account for the surface flux biases, suggest improvements in the model formulations, and re-analyze the new simulations based on the improved physical parameterizations.

WORK COMPLETED

All of the tasks associated with Part 1) of the APPROACH have been completed. This analysis was performed on a 15-year simulation from the NOGAPS model (3.4) conducted by Dr. T. Hogan (NRL).

All of the tasks associated with Part 2) of the APPROACH have been completed. This research involved collaboration with Dr. R. Weller (WHOI), Dr. M. McPhaden (PMEL), Dr. R. Cess (SUNY), M. Medovaya (SUNY), and Dr. B. Wielicki (NASA).

The research associated with Part 3) of the APPROACH is presently underway and a number of high-resolution (3-km) COAMPS simulations and associated variational analyses on the "synthetic soundings" have been completed. This research involves collaboration with Dr. J. Ridout (NRL), Dr. S. Xie (LLNL), Dr. M. Zhang (SUNY).

With respect to Part 4) of the APPROACH, collaboration with Dr. J. Ridout (NRL) has resulted in the analysis of a number of convection parameterization sensitivity tests in a research version of NOGAPS to try and correct the shortcomings in the convective parameterization. While a number of cases show

noteworthy improvements (see WWW address above), continuation and implementation of this work has awaited more elaborate testing in an operational-like setting of NOGAPS which can only be performed by the Global Modeling Section. This additional testing is to ensure that in addition to improvements obtained by the given changes in the convective parameterization, no other aspects of the model predictive skill suffer (e.g., tropical cyclones, frontal systems, etc.). In addition, re-analysis of the surface heat biases of the most recent version of NOGAPS has awaited the production and/or availability of one or more climate simulations with this model (e.g., via AMIP II).

RESULTS

The results pertaining to Part 1) of the APPROACH were described in previous reports and can now be found in Waliser and Hogan (2000).

The results pertaining to the first phase of Part 2) of the APPROACH were described in last year's report and can be found in Waliser et al. (1999a). The results from the second phase involve a more robust and widespread analysis of buoy-derived shortwave data based on two methods developed to isolate clear-sky samples from buoy observations and a comparison of these data to a well-validated model of clear-sky surface shortwave. This analysis was performed on nearly all the available research-quality buoy shortwave data sets, many of which were ONR sponsored. The results of the analysis shows that several moored shortwave records exhibit relatively large clear-sky biases (Fig. 1). Some of these can be explained by unaccounted for aerosol variability in the model calculations. However, a number of them appear to be strongly affected by aerosol build-up on the sensor and/or buoy tilt, the latter of which is found to stem from erroneous sensor tilts or current-induced tilting of the mooring. Additional results can be found in Medovaya et al. (2000; see WWW address above).

Preliminary results pertaining to Parts 3) and 4) of the APPROACH can be found at the WWW address listed above.

IMPACT

The results from the NOGAPS analysis (Waliser and Hogan, 2000) point to the convective parameterization as the major shortcoming underlying the model biases in the surface heat fluxes, and indicate how it also negatively impacts the large-scale circulation, the rainfall, surface wind, and cloud fields, and possibly even the simulation of intraseasonal variability. Remedying these shortcomings will: 1) improve NOGAPS physical representation of the atmosphere and extend the skill of its medium range weather predictions, and 2) improve the skill of the oceanographic predictions via the improved simulation and prediction of the surface fluxes.

The added observational support for the suggestion that shortwave absorption by clouds is not properly treated in GCMs (Waliser et al. 1999a) intensifies the need for immediate and continued study into this issue, especially since artificial inclusion of this effect into GCM simulations shows significant effects on the atmospheric circulation and the surface energy budget (Kiehl et al. 1995).

The buoy analyses presented in Waliser et al. (1999a) and Medovaya et al. (2000) help to quantify the uncertainties in buoy observations of surface shortwave under actual operating conditions. These results point the need for additional platform/instrument developments either to limit sensor tilt and/or

measure the tilt of the mooring, along with a need to develop a sensor cleansing mechanism. In addition, when implemented in an operational setting, the methodology developed in these studies allows the working condition of moored shortwave instruments to be monitored in real-time to help detect instrument failure, degradation or bio-fouling that would necessitate immediate maintenance and/or prevent routine maintenance on the sensor when unnecessary.

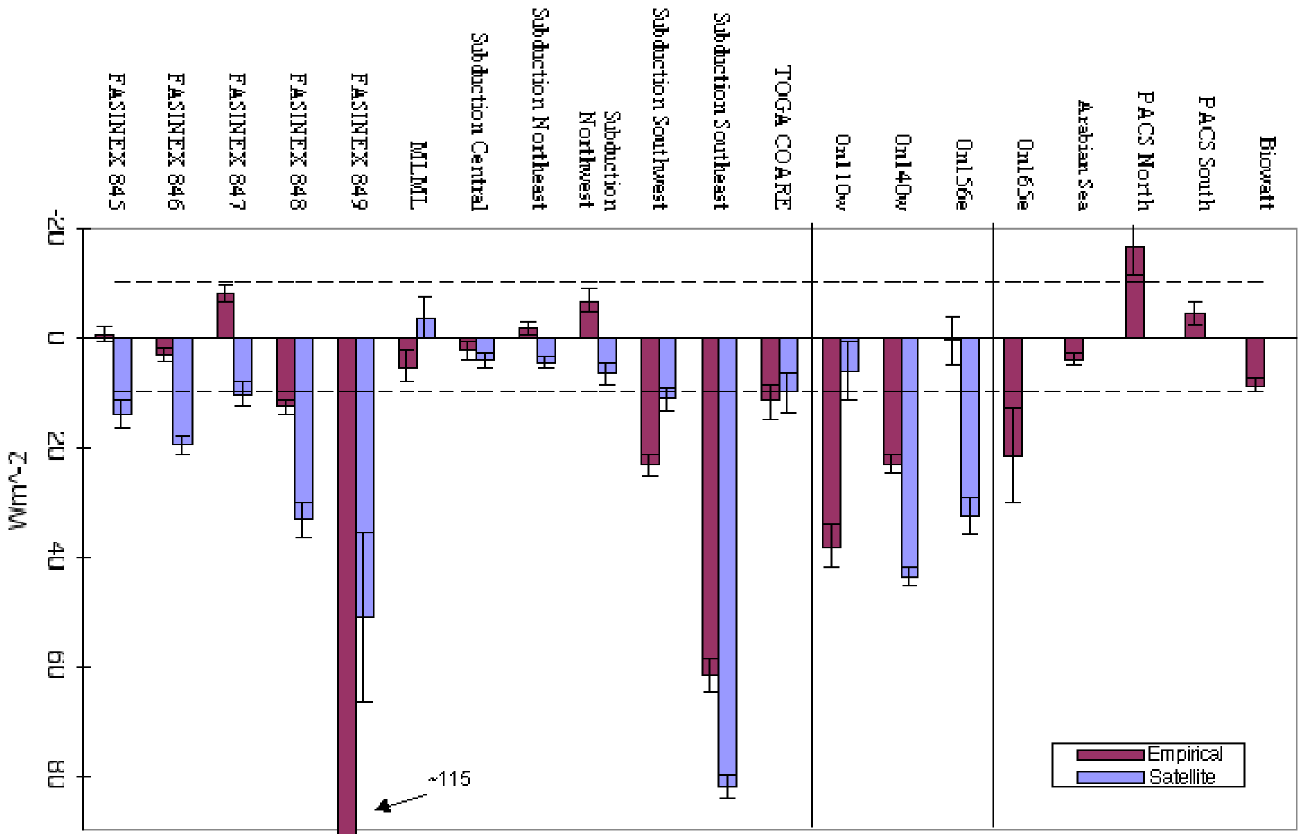

Figure 1. Model versus observed clear-sky shortwave bias using two forms of cloud-filtering. Error bars are 95% confidence levels. The solid vertical lines divide the chart into three categories of buoys: (left) those that had the same length time series for both cloud-filtering methods; (middle) those that had only a limited time-series for satellite-based filtering; (right) that did not have overlapping satellite retrievals. The dashed lines represent very rough limits for acceptable/expected model-data difference.

TRANSITIONS

The analysis of the buoy-derived shortwave data has underscored the need for additional hardware improvements in the way of tilt reduction and/or tilt sensors on buoy deployments that are intended to measure surface shortwave radiation.

RELATED PROJECTS

The PI has also investigated the simulation quality of the Madden-Julian Oscillation (MJO) in the NOGAPS model. This intraseasonal phenomenon has significant influence on tropical rainfall

variability and the onset and breaks of the Asian-Australian monsoons, as well as minor influence on long-range mid-latitude weather forecasts. Preliminary study indicates the NOGAPS model performs poorly with respect to the simulation of this phenomenon, although Slingo et al. (1996) has found that a majority of atmospheric models examined exhibit equally poor MJO simulations.

To help address the shortcomings in model simulations of the MJO, a statistical model for extended-range tropical rainfall has been developed using outgoing longwave radiation (OLR) in an effort to provide a benchmark for the skill of long-range dynamical predictions of the MJO (Waliser et al. 1999b). Comparison of this statistical benchmark with forecasts from the NOAA/NCEP medium-range forecast model shows that the statistical model performs considerably better. These results indicate that considerable advantage might be afforded from the further exploration and eventual implementation of MJO-based statistical models to augment current long-range tropical forecasts. The comparisons also indicate that there is considerably more work to be done in achieving the forecast potential that dynamic models might offer if they could suitably simulate MJO variability (Jones et al., 2000). In addition, the PI has investigated the influence of ocean surface coupling on the simulation of the MJO and found that considerable improvement can be afforded by such coupling (Waliser et al. 1999c). These improvements include: 1) increased variability associated with the MJO, 2) a tendency for the MJO time scales to more closely match those found in the observations, 3) a reduced eastward phase speed in the eastern hemisphere, and 4) an increased seasonal signature in the MJO.

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